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# Bidirectional 3.125 Gbps Downstream / 2 Gbps Upstream Impulse Radio Ultrawide-band (UWB) over Combined Fiber and Wireless Link

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**Abstract:** We demonstrate bidirectional fiber and wireless transmission of impulse radio ultra-wideband at 3.125Gbps downstream and 2Gbps upstream. After transmission over 50km fiber and 1.85m wireless link both signals are recovered without errors.

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**OCIS codes:** (060.2330) Fiber optics communications; (060.2360) Fiber optics links and subsystems

## 1. Introduction

Next generation in-home communication systems are expected to offer wireless connectivity at bit rates exceeding 1Gbps in order to support bandwidth intensive services such as high-definition 3-dimensional TV, video-on-demand and on-line gaming. Scaling present-day wireless technologies based on modulation of a powerful radio frequency (RF) carrier to bit rates higher than 1Gbps may lead to excess power consumption and high levels of radiated radio frequency (RF), with potential health and safety issues as a consequence. Ultra-wideband (UWB) provides data rates of several Gbps while maintaining very low RF emission levels ( $< -41.3\text{dBm/MHz}$  from 3.1 to 10.7GHz according to FCC regulations [1]), relying on either orthogonal frequency division multiplexing (OFDM), or on impulse radio (IR) making use of short pulses with a spectral shape complying with the requirements specified in [1]. Wireless IR-UWB transmission over 4 meters at 4Gbps has been presented in [2]. Due to the low RF power levels wireless range is limited to a few meters, and photonic transmission to and from the central office through a fiber network is desirable. Examples of optical generation and transmission of IR-UWB signals are presented in [3, 4]. Bidirectional fiber transmission of 480Mbps UWB signals have been presented using OFDM in [5]; however only with unidirectional wireless transmission over 1m. In order to fully harness the potential of UWB systems, bidirectional wireless transmission at bit rates exceeding 1Gbps is a requirement.

In this paper we present, to the best of our knowledge, the first IR-UWB system sporting true bidirectionality in the optical as well as in the wireless domain. 50km fiber and 1.85m wireless transmission of IR-UWB signals at 3.125Gbps downstream and 2Gbps upstream is presented.

## 2. Experimental Setup

Fig. 1 shows the experimental setup. For the downstream channel, the signal is generated at the central office, where photonic IR-UWB signal generation is employed. A 1553.2nm external cavity laser (ECL) intensity modulated at 12.5Gbps is injected into the first-order sidemode of a distributed feedback (DFB) laser with center-wavelength 1552.1nm. The data pattern is constructed from a pseudo random bit sequence (PRBS) of wordlength  $2^7 - 1$  in such a way that a UWB "0" bit is represented by the pattern "0000" and a UWB "1" bit is represented by the pattern

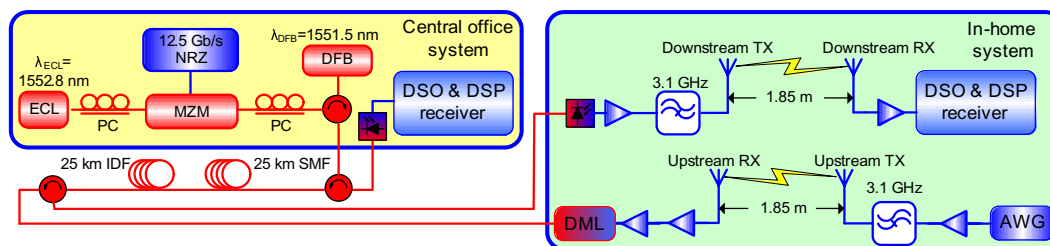


Fig. 1. Simplified block diagram of the setup used in the experiment.

"1000". Due to cross gain modulation (XGM) in the DFB laser and the associated carrier relaxation oscillations, the incoherent summation of the ECL and DFB optical fields creates a 3.125Gb/s IR-UWB signal [3].

After 50 km fiber transmission, the downstream signal is detected by a photodiode (PD), amplified, and high-pass filtered in order to comply with the US Federal Communications Commission (FCC) indoor requirements [1] before it is led to an omnidirectional UWB antenna with a peak gain of 4.5dBi at 4.5GHz. After 1.85 m wireless transmission, the downstream signal is received by a bow-tie phased array directional antenna with gain varying from 4.65dBi to 12.5dBi in 3.1-10.6GHz. The received signal is amplified by a low noise amplifier with 30dB gain, and sampled by an Agilent 40GSa/s digital storage oscilloscope (DSO). Demodulation and bit error ratio (BER) calculation is performed offline using a digital signal processing (DSP) algorithm.

For the in-home generated upstream channel, the wireless upstream transmission precedes the fiber transmission. Therefore, electronic generation of the IR-UWB pulses is implemented using a Tektronix arbitrary waveform generator (AWG). A 5th derivative Gaussian pulse shape of standard deviation 60ps is used due to its excellent compliance with the FCC mask. The upstream bit rate is 2Gbps and the PRBS wordlength is  $2^{11} - 1$ . The wireless link for the upstream transmission is identical to the one used for the downstream transmission. The receiver and transmitter antenna units are integrated within a 20 x 25 cm package, with the interface between the two antennas covered with absorbing material. In order to further reduce crosstalk between the upstream and downstream signals, the upstream wireless signal is vertically polarized, and the downstream wireless signal is horizontally polarized. After wireless transmission, the signal is amplified, led to a directly modulated laser with a wavelength of 1550.6nm, and transmitted upstream through the fiber link. Finally, the upstream signal is received with a DSP-based receiver. Optical launch power into the fiber is 3.0dBm for the upstream signal, and 1.3dBm for the downstream signal. Total fiber loss is 11.7dB.

### 3. Results

The electrical spectra at the input of the transmitter antennas are shown in Fig. 2 for the 2Gbps upstream signal (a) and for the 3.125Gbps downstream signal (b), together with the FCC mask. Also plotted is the FCC mask when the response of the transmitting antenna is taken into account. This is calculated according to the method described in the [4]. Good compliance with the FCC regulation for the downstream as well as for the upstream signal is observed. Peak power within a 50MHz bandwidth is less than 0dBm, as specified in [1].

The upstream signal corresponding to the pattern '1010110' is plotted in Fig. 3 (a) for the upstream signal alone and in Fig. 3 (b) with the counter-propagating upstream signal. The signals at the output of the photonic IR-UWB generator, after the wireless transmission, and after both wireless and fiber transmission are plotted. Similarly, in Fig. 3 (c) and (d) the downstream signal with and without the upstream is plotted at the transmitting antenna input, after the wireless transmission, and after both wireless and fiber transmission. From the isolated '1' in bit No.3 the IR-UWB pulse-shape can be clearly identified. The wireless and optical transmission is seen to cause negligible signal degradation, and only small signal degradation is observed from the counter-propagating signal. All signals were demodulated with no errors in the 200.000 bits analyzed.

In order to estimate a power budget for the optical downstream transmission, a BER vs. receiver optical input power

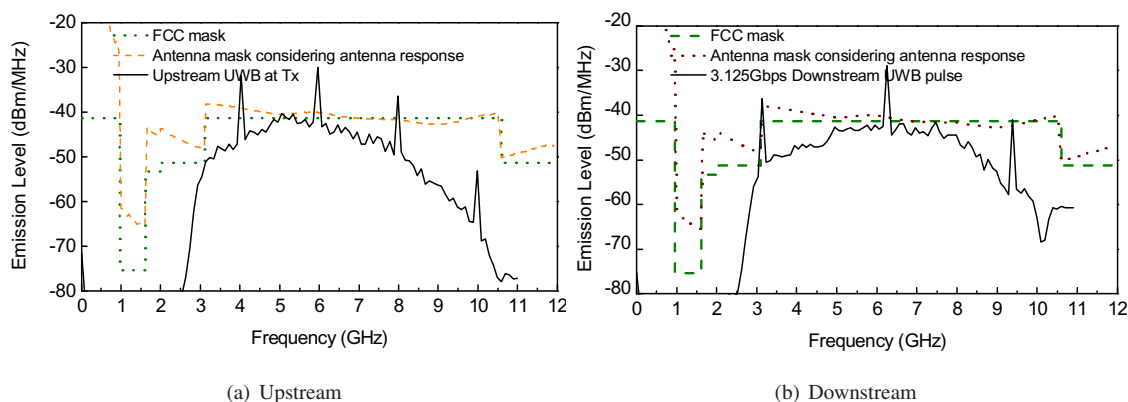


Fig. 2. Electrical spectra at antenna input for the 2Gbps upstream signal (a) and the 3.125Gbps downstream signal (b).

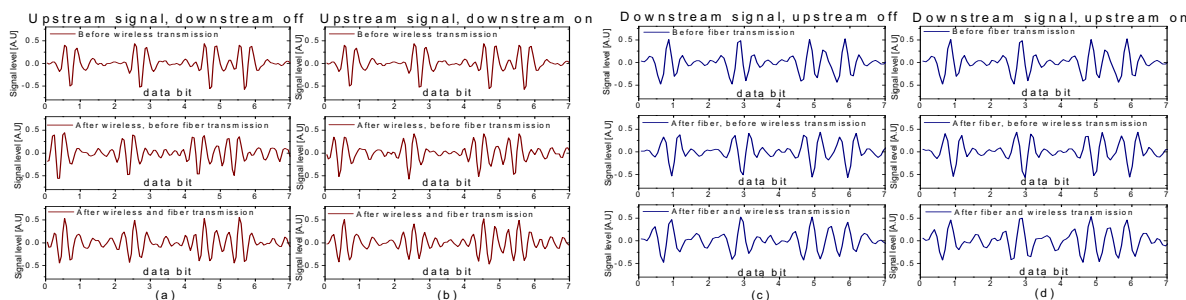


Fig. 3. The signals corresponding to pattern '1010110' at key positions in the signal path. Upstream signal alone (a), upstream signal with downstream signal (b), downstream signal alone (c), and downstream signal with upstream signal (d).

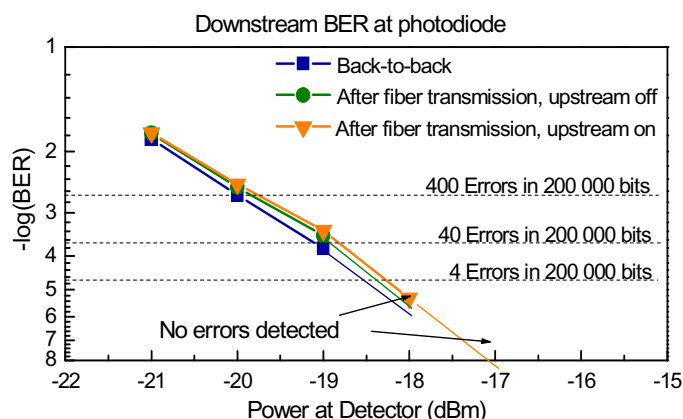


Fig. 4. Measured BER of the downstream signal before and after optical transmission, with and without the counter-propagating upstream signal.

measurement was performed. The result is plotted in Fig. 4 before and after fiber transmission, with and without the counter-propagating upstream signal. Without the upstream signal, no errors were detected with -18dBm into the PD; with the upstream signal, no errors were detected with -17dBm. Using the forward error correction limit of a  $\text{BER} < 10^{-3}$ , a receiver sensitivity of -19.5dBm was found in all three cases. Optical power of the downstream signal after the fiber was measured to -10.5dBm, so a 9dB power budget margin was found for the optical downstream signal, corresponding to e.g. the loss of a 1:8 power splitter.

#### 4. Conclusion

We have successfully demonstrated for the first time bidirectional fiber and bidirectional wireless transmission of IR-UWB signals at 3.125Gbps downstream and 2Gbps upstream. Both signals were received with no errors in 200.000 bits analyzed using a DSP receiver. These results demonstrate IR-UWB as a strong candidate for future low emission high speed bidirectional wireless personal area networks.

#### 5. Acknowledgements

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